
NBS REPORT

7921

# TENTH PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

for

Period Ending June 30, 1963

NBS




U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

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A complete listing of the Bureau's publications can be found in National Bureau of Standards Circular 460, Publications of the National Bureau of Standards, 1901 to June 1947 ($1.25), and the Supplement to National Bureau of Standards Circular 460, July 1947 to June 1957 ($1.50), and Miscellaneous Publication 240, July 1957 to June 1960 (includes Titles of Papers Published in Outside Journals 1950 to 1959) ($2.25); available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

# NATIONAL BUREAU OF STANDARDS REPORT

| NBS PROJECT | | NBS REPORT |
|---|---|---|
| 8120-12-81410<br>8120-40-81420<br>8150-12-81430<br>8140-40-81450<br>8120-40-81520 | June 30, 1963 | 7921 |

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## IMPORTANT NOTICE

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## Publications

(Papers and Reports published under the NASA Contract, that have become available during the current reporting period.)

1. Pressure-density-temperature relations of fluid para hydrogen from 15 to 100°K at pressures to 350 atmospheres, by Robert D. Goodwin, Dwain E. Diller, Hans M. Roder, and Lloyd A. Weber. J. Res. (Part A-Physics and Chemistry), Natl. Bur. Std. 67A, No. 2, 173-192, Mar-Apr, 1963.
2. The orthobaric densities of parahydrogen, derived heats of vaporization and critical constants, by H. M. Roder, D. E. Diller, L. A. Weber, and R. D. Goodwin. Cryogenics 3, No. 1, 16-22, Mar. 1963.
3. Pressure-density-temperature relations of freezing liquid parahydrogen to 350 atmospheres, by R. D. Goodwin and H. M. Roder. Cryogenics 3, No. 1, 12-15, Mar. 1963.
4. A bibliography of thermophysical properties for fluorine from 0° to 300°K, by L. A. Hall and R. D. McCarty. NBS Report 7676, April 1, 1963.
5. Thermal conductivity of ten cryogenic liquids, a bibliography, by L. A. Hall. NBS Report 7684, April 15, 1963.
6. A survey of the P-T loci of compressibility (P-V-T) data for helium, hydrogen, neon, nitrogen, carbon monoxide and oxygen at low temperature, by Robert D. Goodwin. NBS Report 7680, March, 1963.

| STAGE OF COMPLETION ↑ / TASK 81410 → | Liquid Level Transducer Program - 1st Phase | Liquid Level Transducer Program - 2nd Phase | Liquid Level Transducer (work statement and costs) | Pressure Transducers 1st Phase | Pressure Transducers 2nd Phase | Pressure Transducers (work statement and costs) | Temperature Transducer Test Program 1st Phase | Temperature Transducer Test Program 2nd Phase | Temperature Transducer (work statement and cost) | Flow Measurement Calibration Facility (Recommendations) | Density Measurement 1st Phase | Density Measurement (Forced vibration densitometer) | Density Measurement 2nd Phase | Density Measurement (work statement and costs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimated Completion Date | 8-31-63 | 5-17-63 | | | 5-17-63 | | 12-31-63 | 5-17-63 | | 5-15-63 | | | 5-17-63 | |
| Phase Completed * | | X | | X | X | | | X | | X | X | | X | |
| Report Being Printed | | | | | | | | | | | | | | |
| Final Report Finished | | | | | | | | | | | | | | |
| Report Started | X | | | | | | | | | | | | | |
| Data & Analysis of Data Compiled | | | | | | | | | | | | | | |
| Analysis Completed | | | | | | | | | | | | | | |
| Analysis of Data Started | X | | | | | | X | | | | | | | |
| Data Completely Taken | X | | | | | | | | | | | | | |
| Data Taking ½ Finished | | | | | | | | | | | | | | |
| Rig Operating & Data Taking Started | | | | | | | X | | | | | | | |
| Theory Set Down | | | | | | | | | | | | | | |
| Rig Is Built | | | | | | | | | | | | | | |
| Rig Is Designed | | | | | | | | | | | | | | |
| Initial Phase of Planning Complete | | | | | | | | | | | | | | |
| Will Not Do or Shelved | | | | | | | | | | | | | | |
| Not Started As Yet | | | | | | | | | | | | | | |
| Active Coord. With Lewis, MSFC, LASL | X | X | | | X | | X | X | | X | | | X | |
| Item Number | | | | | | | | | | | | | | |

| Item Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TASK → 81430 Parahydrogen | PVT Data | Virial Coefficients | Equation of State | Final Thermodynamic Functions | First Derivatives of PVT Data | Joule-Thomson Inversion Curve | Sonic Velocities (Derived) | Vapor Pressure Equation | Orthobaric Densities | Heats of Vaporization | The Melting Line | Parahydrogen Review | PVT Review Other Fluids | Experimental Viscosities | Experimental Sonic Velocities | Experimental Dielectric Constants |
| Estimated Completion Date | 3-63 | 6-63 | --- | 12-63 | | | 8-63 | 1962 | 1963 | 1963 | 12-63 | | 9-63 | 1965 | 1966 | 1964 |
| Phase Completed * | X | | | | | | | X | X | X | | | | | | |
| Report Being Printed | X | | | | | | | | | | | | | | | |
| Final Report Finished | | X | | | | | X | | | | | X | | | | |
| Report Started | | | | X | X | X | | | | | | | X | | | |
| Data & Analysis of Data Compiled | | | | | | | | | | | X | | | | | |
| Analysis Completed | | | | | | | | | | | | | | | | |
| Analysis of Data Started | | | X | | | | | | | | | | | | | |
| Data Completely Taken | | | | | | | | | | | | | | | | |
| Data Taking ½ Finished | | | | | | | | | | | | | | | | |
| Rig Operating & Data Taking Started | | | | | | | | | | | | | | X | | X |
| Theory Set Down | | | | | | | | | | | | | | | | |
| Rig Is Built | | | | | | | | | | | | | | | 1/2 | |
| Rig Is Designed | | | | | | | | | | | | | | | | |
| Initial Phase of Planning Complete | | | | | | | | | | | | | | | | |
| Will Not Do or Shelved | | | | | | | | | | | | | | | | |
| Not Started As Yet | | | | | | | | | | | | | | | | |
| Active Coord. With Lewis, MSFC, LASL | | | | | | | | | | | | | | | | |

STAGE OF COMPLETION ↑

| STAGE OF COMPLETION ↑ / TASK → 81420 and 81520 | Consultation and Advisory Services | Rover 81420 General Consultation | Nerva 81420 General Consultation | Centaur 81520 General Consultation | Engine Cooldown | Subcooled Hydrogen | Stratification & pressure rise |
|---|---|---|---|---|---|---|---|
| Estimated Completion Date | | * | * | * | | * | * |
| Phase Completed * | | | | | X | | |
| Report Being Printed | | | | | | | |
| Final Report Finished | | | | | | | |
| Report Started | | | | | | | |
| Data & Analysis of Data Compiled | | | | | | | |
| Analysis Completed | | | | | | | |
| Analysis of Data Started | | | | | | | |
| Data Completely Taken | | | | | | | |
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| Theory Set Down | | | | | | | |
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| Rig Is Designed | | | | | | | |
| Initial Phase of Planning Complete | | | | | | X | X |
| Will Not Do or Shelved | | | | | | | |
| Not Started As Yet | | | | | | | |
| Active Coord. With Lewis, MSFC, LASL | | X | X | X | X | X | X |
| Item Number | | | | | | | |

* Continuing Effort

# 1. Physical Properties of Hydrogen

## 1.0 Clearing House for Information on Hydrogen Properties

R. J. Corruccini

### 1.0.1 Energy Storage Mechanisms in Liquid Hydrogen

Attention is directed to a report of 31 October 1962 with the above title by H. G. Carter, Nuclear Aerospace Research Facility, General Dynamics/Fort Worth. The 129 page report is identified as Doc. No. NARF-62-15T/FZK-9-180, Contract AF 33(657)-7201 and is available from ASTIA as AD 293 885. Following is an abstract of the report.

"Energy-storing molecular products of radiation in liquid hydrogen are examined from the point of view that the expulsion of potential energy in the form of such products may lead to lower design weights for nuclear rockets. It is found that a significant fraction of the energy deposited by radiation in liquid hydrogen is stored temporarily through the dissociation and excitation of $H_2$ molecules. Experimental and theoretical results are consistent with a rate of dissipation of such energy into thermal motion which is much slower than the rate at which the radiation products are expelled from the tank. It is shown that, if this is the case, relatively high levels of infrared radiation are to be expected but that such energy will not rapidly be translated into thermal motion. It is concluded that, insofar as radiation heating of the propellant is a significant design factor, further consideration should be given to radiation-induced reactions in liquid hydrogen and that any radiation-heating experiments should be interpreted in terms of possible energy-storage effects."

## 1.1 Thermodynamic and Transport Properties

R. D. Goodwin, D. E. Diller, H. M. Roder, L. A. Weber and B. A. Younglove

Current status of work on the properties of parahydrogen is summarized by table 81430.

New low-temperature instrumentation is about 50% completed. It will permit simultaneous conduct of two experimental programs.

About 300 individual viscosity measurements have been obtained. Some small irregularities in the viscosity data are attributed to sonic resonances. Equivalent measurements with a quartz crystal of different dimensions therefore are planned.

The known sonic velocity of water has been duplicated with apparatus being designed for low-temperature hydrogen.

Measurements of dielectric constant by Dr. John W. Stewart under NBS support are about 80% completed.

In final manuscript form is the publication on thermodynamic and related properties as computed by numerical methods. Work continues on the difficult problem of analytical representations of the virial coefficients which will be acceptable both practically and theoretically. The status of publications otherwise is the same as detailed on page 4 of the Ninth Progress Report, NBS Report 7671, March 31, 1963. Other publications on parahydrogen are available through the NBS Cryogenic Data Center, Boulder, Colorado.

## 2. Cryogenic Instrumentation

### 2.0 General Comments

Personnel contributing to this activity during the reporting period were: W. J. Alspach, D. A. Burgeson, T. M. Flynn, C. E. Miller and R. J. Richards.

A rough draft proposal including cryogenic instrumentation activities which could be performed by C. E. L. D. for N. A. S. A. with Fiscal 1964 funds was forwarded to Mr. William A. Olsen on May 17, 1963.

A summary of work completed or in process during this quarter is described in the following sections.

### 2.1 Temperature Transducer Test Program

Upon the request of the sponsoring agency, a review of the existing temperature transducer program was made and plans for expanding the efforts were formulated. The first phase of the proposed program will be to initiate experimental tests on commercially available transducers in order to provide performance data in areas where such data are sparse or nonexistent. A long range analytical program will run concurrently to complement the test programs. Several of the selected topics which have been singled out for investigation are:

a. Influences of electromagnetic radiation

b. Pressure sensitivity of transducer

c. Effects of vibration

d. Transducer dynamic characteristics

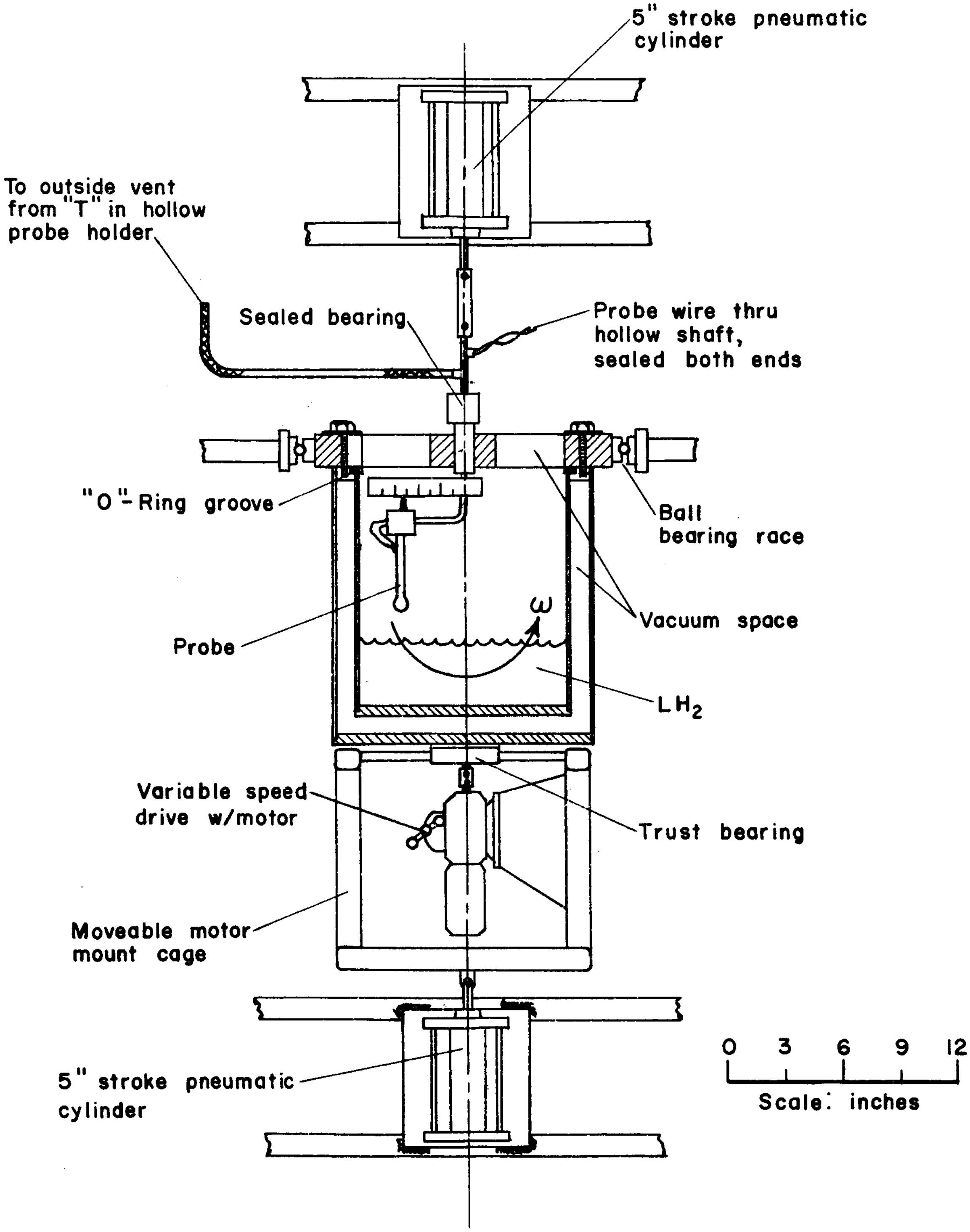
e. Study of installation techniques.

The existing temperature transducer program (see progress reports 1-8) has been principally confined to a theoretical study concerned with predicting the dynamic characteristics of temperature transducers. While results have been encouraging, the study is presently viewed as a long range program. The experimental apparatus presently in operation was designed primarily to provide data to be used in conjunction with the theoretical effort. The apparatus is complex, requires a great deal of set-up time, and in general is not suited for rapid testing of commercial transducers. In addition, the nature of the test requires that the pressure sensitivity and effects of mechanical shock be known in order for the test results to be meaningful. Accordingly, a simpler test program has been initiated in order to provide a rapid but meaningful dynamic test. The objective of the proposed test is two-fold.

1. To subject a number of commercial transducers to a uniform test which heretofore has not been done.
2. To provide a means of comparing the dynamic characteristics of the various type transducers on the basis of
    a. principle of operation
    b. physical characteristics.

The apparatus being designed for this test is shown in Figure 2.1.1. The system which utilizes the rotating vessel principle has often been used by others concerned with dynamic testing of temperature transducers. Several of the important features of this particular system are:

1. May be used both for hydrogen and nitrogen service.
2. Both forced and natural convective heat transfer conditions can be achieved.




Time - Temperature Response Apparatus

FIG. 2.1.1

3. May accommodate a large variety of transducers.

4. Temperature perturbation can be achieved by either plunging the sensor into the rotating vessel or fixing the transducer and raising the dewar. This capability has been designed into the system to enable the effects of mechanical shock to be determined.

5. The simplicity of the system will facilitate rapid testing of the transducers.

Design of the apparatus is near completion and fabrication will begin in the near future.

The heat transfer simulator discussed in the preceding report has been completed and initial studies have been conducted. The analog uses a ten-node R-C network to provide transient solutions to the Fourier heat transfer equation. High impedance amplifiers were specially designed and integrated into the computer to provide accurate voltage measurement at each of the ten nodes. Circuit resistance and capacitor elements may be readily changed to facilitate the solution of the various mathematical models which are being considered. Figure 2.1.2 is a plot showing a comparison between the simulator solution and a solution obtained using digital techniques. It will be noted that good agreement exists between the two solutions. A manually operated arbitrary function generator has been designed and will be employed to obtain solutions involving time variant boundary conditions.

Attempts to prove the validity of the mathematical model have to date been unsuccessful. This is due principally to the problems associated with calculating film coefficients. While some degree of success has been realized for ambient temperature fluids, findings of a recent state-of-the-art survey (NBS Technical Note 122) show that adequate methods do not exist for calculating forced or natural convective parameters in cryogenic fluids. This is particularly true when the geometry of the object is not well defined. For this reason it is recommended that a program aimed at investigating this fundamental problem be initiated. It is argued that until significant progress on this problem is made, the development of a practical mathematical theory for predicting dynamic characteristics of temperature sensors will be hindered.

During the next quarter, plans for the future test programs will be finalized and design and development of hardware begun.

## 2.2 Pressure Transducer Program

### 2.2.1 Commercial Transducer Test Program

All tests on the original group of instruments have been completed. The plotted data are shown on graphs in the 5th and 6th Quarterly Reports (NBS Report Nos. 7246 and 7279).

### 2.2.2 A Carbon Resistor Pressure Transducer Test Series

The piezoresistive nature of carbon has been frequently used as a transducer in the measurement of pressure and other parameters which can cause mechanical stressing. Recently, several tests were conducted on commercially available carbon composition resistors for the purpose of investigating their potential application as a transducer. The information obtained from these tests has been encouraging, however, additional data is needed in order to more fully establish its characteristics. One of the more apparent and perhaps outstanding features of the resistor is its low cost. In addition, resistors are readily accessible and it appears that their use as a transducer would not require a great deal of skill. The following is a list of preliminary data and observations obtained from tests conducted on ordinary 1/10 and 1/4 watt carbon composition resistors.

Linearity

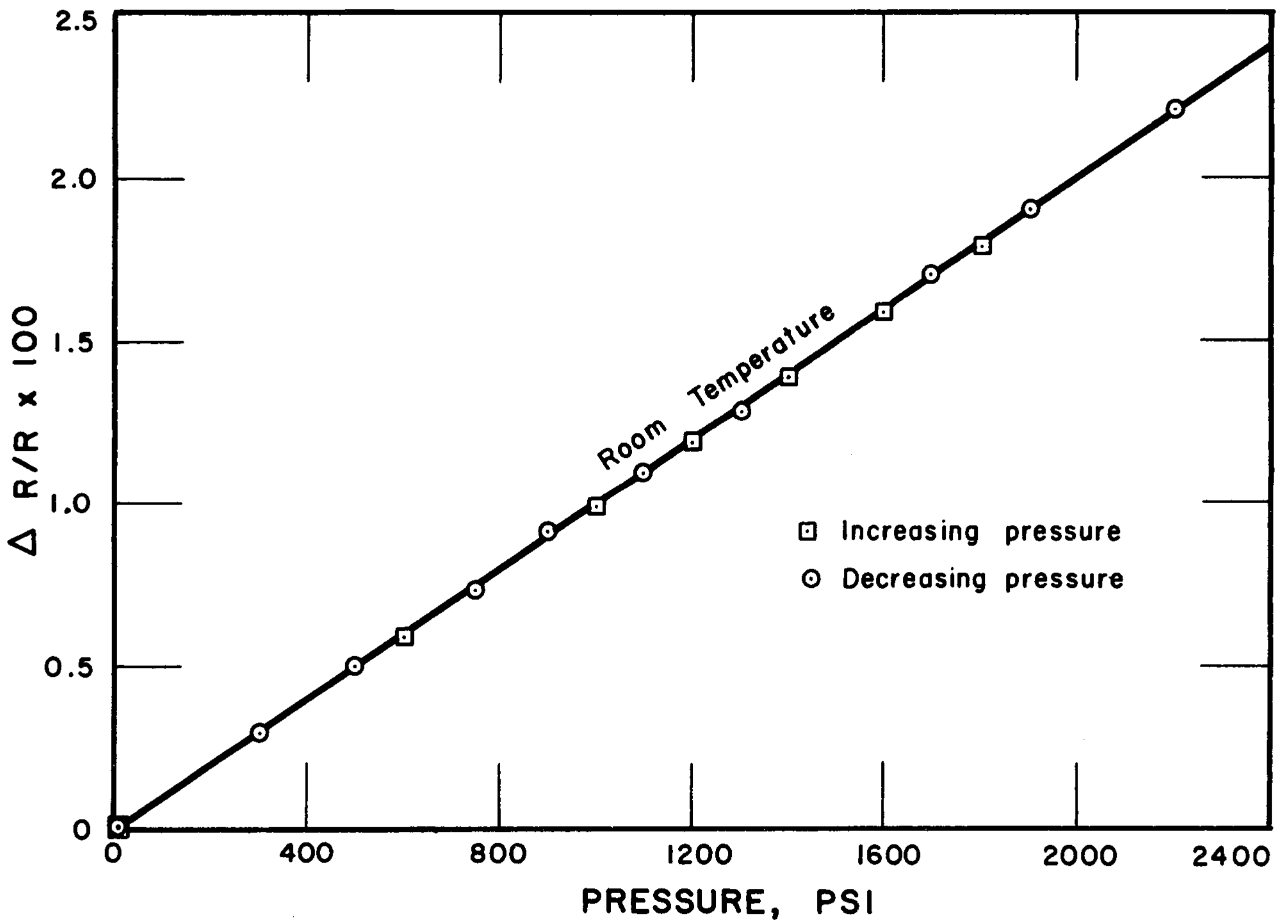
Figure 2. 2. 2. 1 shows a typical calibration curve for a 1/10 watt Ohmite resistor. The data shown were obtained by placing the resistor in a chamber and pressurizing. Similar results were obtained when the resistor was mechanically stressed (application of a point load). Data points were taken for increasing and decreasing pressures for determining hysteresis. Figure 2. 2. 2. 2 shows a plot at the percent deviation of full scale taken from a best straight line fit of the data. It should be pointed out that the preliminary data shown was obtained with equipment of unverified accuracy and hence should not be construed as exact linearity data. Future tests, using precise equipment, will be conducted to establish a true linearity value. Results show the resistor is linear within ± 1 percent of full scale.

Dynamic Characteristics

Figure 2. 2. 2. 3 presents the results of tests in which a resistor and precision strain gage transducer were simultaneously subjected to a ramp change in pressure. Note that both transducers responded similarly to the high frequency pressure perturbations. The apparent increase in output of the carbon resistor after the strain gage reaches steady state is caused by a temperature effect resulting from adiabatic compression of the gas. The high dynamic response is believed to exist by virtue of the resistors low mass and high stiffness.

Repeatability

Pressure cycling the resistor has shown it to be repeatable as long as the resistor is not overstressed. A resistor epoxied into a metal block was cycled more than 50 times without causing any measurable change in its characteristics.




Pressure vs. Resistance Change
for 1/10 watt Ohmite Resistor

FIG. 2.2.2.1

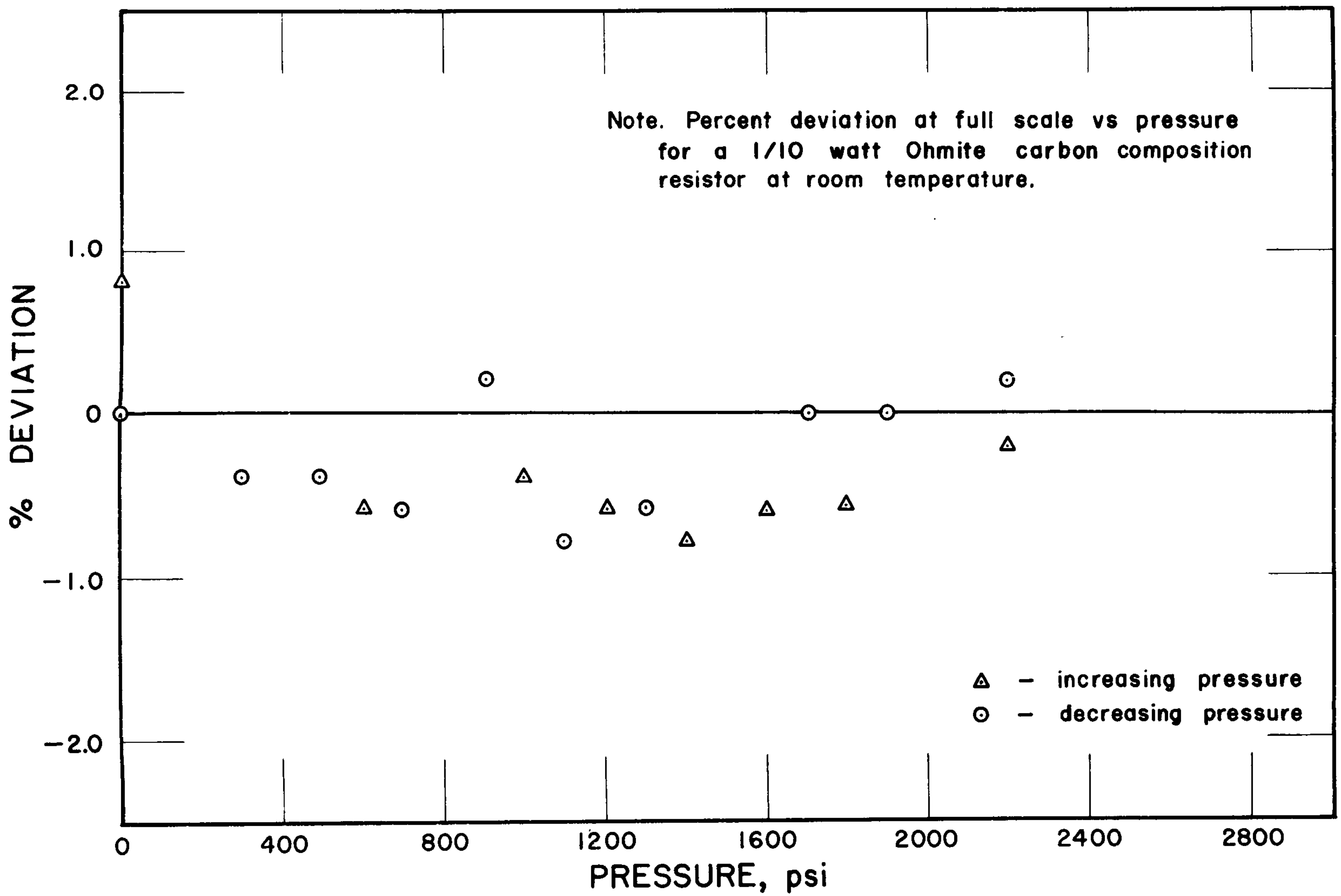
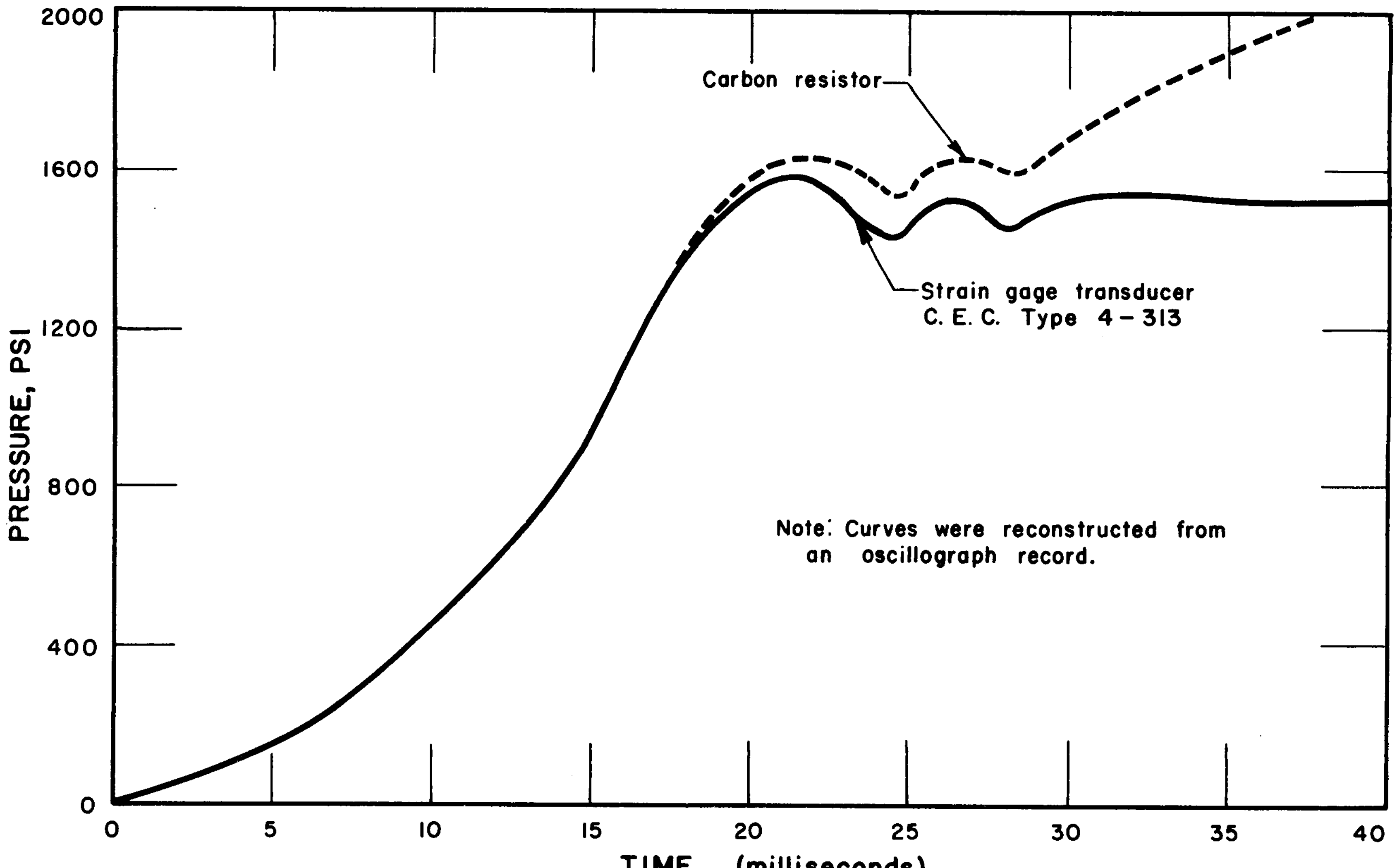

Note. Percent deviation at full scale vs pressure for a 1/10 watt Ohmite carbon composition resistor at room temperature.
% DEVIATION
2.0
1.0
0
−1.0
−2.0
PRESSURE, psi
0
400
800
1200
1600
2000
2400
2800
△ – increasing pressure
⊙ – decreasing pressure

FIG. 2.2.2.2




Dynamic Response of a Carbon Resistor

FIG. 2.2.2.3

Sensitivity

The percent change, ($\Delta r/r$), for a resistor stressed by a fluid appears to be approximately 1%/1000 psi, but large stresses can be generated with relatively small forces due to the small physical sizes of low power resistors. This points out the possibility of using the resistor for measuring small pressure.

Temperature Sensitivity

The temperature sensitivity of commercial carbon composition resistors at room temperature is nominally about 500 ppm/°C. While this might appear prohibitively large, the strain sensitive resistors may be temperature compensated using familiar temperature bridge compensating techniques. Calibration of a temperature uncompensated resistor at $LN_2$ temperatures showed that its sensitivity (change in resistance divided by change in pressure) remains essentially independent of temperature. However, a sizeable zero shift does occur between room and $LN_2$ temperatures, as would be expected.

It is believed that the above data, although incomplete, is sufficient to warrant additional evaluation of the resistor. Several topics which remain to be investigated are:

1. Creep - long term stability
2. Determination of the gage factor
3. Determination of the most advantageous stressing techniques.

### 2.3 Liquid Level Transducer Program

#### 2.3.1 Transducer Testing

The testing program and data reduction have been completed for all repeatability and time response tests.

A preliminary report containing the data on all but the last group of sensors has been written and a restricted number of copies supplied to W. A. Olsen and Andrew Stofan of NASA LeRC for their distribution.

Each vendor participating in this program has received test data and circuit analysis on his respective transducer and controller for comment prior to publication of the NBS final report.

Pertinent comments from vendors will be included in the final report which is now in preparation.

The final report completion date has been changed in order to include additional testing data on General Dynamics/Astronautics transducers. The new completion date is August 31, 1963.

Test data, and experience gained from this test program were applied in the evaluation of proposed propellant utilization systems for "Centaur". A summary of this consultation is included in Section 3.

An abstract of a paper titled "The Performance of Point Level Sensors in Liquid Hydrogen" based on the above work was submitted to and accepted by the 1963 Cryogenic Engineering Conference committe. Preparation of this paper for presentation at the conference in August, 1963, was started during this period.

### 2.4 Density Measurement

A literature survey of density meters has been started in order to determine current status. It is anticipated that a background in this subject will be required before further research should be undertaken.

### 2.5 Flow Measurement

A final report "Recommendations to the National Aeronautics and Space Administration Concerning a Cryogenic Fluid Flowmeter Calibration Facility" (NBS Report 7692) was completed on May 15, 1963. The report was reviewed by NBS Washington and distributed to various governmental agencies designated by Mr. Paul Ordin, SNPO-C.

At Washington, D. C. on May 24, 1963, a verbal presentation summarizing the report was made to a representative group of those on Mr. Ordin's distribution list. A discussion period followed the presentation. Final review of the recommendations is continuing in NASA.

## 2.6 Contractor Liaison

### 2.6.1 Visitors to NBS-CELD

Mr. Harlan D. Burke of NASA-MSFC M-ASTR-IM visited NBS-CELD to discuss temperature measurement. Mr. Burke was interested in determining the status of the NBS-CELD program and how it might be integrated into the "Saturn" program. Mr. Burke was informed of current and proposed efforts.

M. C. Harrold and I. Alne of LMSC, Santa Cruz, California, visited NBS-CELD to discuss cryogenic instrumentation of the RIFT simulator (9 foot tank ).

### 2.6.2 NBS Visits to Contractor Facilities and NASA-LeRC

One trip was made to the Santa Susana Test Facility of North American Rocketdyne on April 18, 1963. The purpose of the visit was to obtain an "up-to-date" status report on the N. A. A. Flow Calibration Facilities and to discuss cryogenic flow calibration requirements. Tentative NBS-CELD recommendations were discussed.

N. A. A. expressed a need for a standard calibration facility which they could use.

Trips and consultation to other facilities are reported in Section 3.

## 3 Consultation and Advisory Services

D. B. Chelton

Consultation and advisory services in the general field of cryogenic engineering has continued on two NASA program areas; Project Centaur (funded separately) and Projects Rover and Nerva.

### 3.1 Project Centaur

General assistance was given to NASA, Lewis Research Center and General Dynamics/Astronautics (GD/A) in several areas, some of which were of a minor nature and will not be discussed in detail. Specific areas in which a relatively concentrated effort was placed are discussed below.

As a result of a proposal to precool the Centaur engines with liquid helium prior to launch, assistance was given in evaluating the related problems from the standpoints of thermodynamics, heat transfer and logistics. A recommendation was given to NASA for an alternate method of chilldown using gaseous helium cooled to liquid hydrogen temperature. The advantages and disadvantages of both procedures were indicated.

The rate of pressure rise in the Centaur fuel tank is greater than would be anticipated if the contents were in thermal equilibrium. The mechanism governing the phenomenon of pressure rise is now being studied. Specific experiments to assist in the evaluation are being performed by GD/A. Additional tests are being considered by NBS.

The use of subcooled liquid hydrogen is being considered to increase payload capabilities. A study is being made of the feasibility of providing various degrees of subcooling on the launch pad. Preliminary estimates of the required ground support equipment are included.

In response for the immediate need for the selection of appropriate instrumentation for an advanced propellant utilization system, meetings were attended at GD/A and NASA. Resulting from these meetings, a new system was selected for incorporation on vehicle AC-5. A preliminary report on an experimental program conducted by this laboratory for the evaluation of cryogenic liquid level point sensors was provided to NASA.

To fulfill the above tasks, a total of three trips were made to GD/A, San Diego and two trips were made to NASA, Cleveland. In addition several visits were made by personnel of the above organizations to NBS.

### 3.2 Project Rover

General assistance was given to the Los Alamos Scientific Laboratory (LASL) in several areas of cryogenic interest. These included the subjects of fluid properties, mechanical properties of solid materials, insulation and ground support equipment.

### 3.3 Project Nerva

Preliminary contacts have been made with NASA personnel in an effort to establish a mechanism for the review of Nerva instrumentation problems and requirements. The feasibility of this laboratory reviewing specifications, drawings and plans for cryogenic equipment requirements was also explored. It is anticipated that we will proceed on both items.

## 4. The Compilation of Thermophysical Properties of Cryogenic Materials

R. B. Stewart and V. J. Johnson

This project is engaged in the evaluation and compilation of thermophysical property data from the technical literature. Tables and graphs of data based on "best values" selected from the literature are compiled for wide ranges of temperature and pressure. A summary of the tasks in progress during the current reporting period follows.

### 4.1 Thermodynamic Properties of the Cryogenic Fluids

The task for the compilation of thermodynamic property data for neon has been essentially completed. A report on the thermodynamic property calculations which includes extensive tables and the P-Z and T-S charts is now undergoing editorial review. A paper on this work has also been accepted for presentation to the Cryogenic Engineering Conference in August, 1963.

The P-V-T data for oxygen, both liquid and gaseous, has been evaluated and fitted to an equation of state for the generation of tables and the calculation of thermodynamic properties. A table of thermodynamic properties has been calculated as a preliminary to its issuance in an NBS Report; thus the report will make these tables available for use while further evaluations are in progress.

The task for the compilation of the thermodynamic property data for carbon monoxide has been essentially completed. The preliminary manuscript of the report on this activity has been revised to include the thermodynamic properties. This report is now undergoing final editorial review and will be published as an NBS Technical

Note. The P-Z and T-S charts from this report are reproduced on the following page. (8-1/2" x 11" and 17" x 22" copies are available from the Cryogenic Data Center).

The activity on the compilation of the thermodynamic properties of argon is being actively pursued during the summer months. This task is assigned to a summer employee who is a Ph. D. candidate during the remainder of the year. It is anticipated that tables of P-V-T values based on the "selected data" from the literature will be made available during the next reporting period.

The task for the compilation of the saturation properties (vapor pressure, saturation densities, latent heats and specific heats at constant saturation - for all phase transitions) is being continued with a high priority.

## 4.2 Additional Thermophysical Properties for Cryogenic Materials

In the task for compiling surface tension data for the cryogenic fluids, new functions are being studied to correlate the data for all cryogenic fluids. (See the Seventh Progress Report for information on an earlier correlation). It is anticipated that more accurate extrapolation of the data will be achieved by the use of this new function for the heavier fluids.

The preliminary report on the dielectric constant of the cryogenic fluids is undergoing final revisions and editorial review. This work has been pursued at a low priority.

The task for compiling electrical resistivity data of the nearly pure metallic elements is continuing. Substantial progress has been made during the current reporting period.

## 4.3 Bibliographies of Selected Topics

The literature search for experimental data on saturation properties of cryogenic fluids is continuing. Approximately 500 references have been accumulated which report experimental data on this subject. Over half of these documents have been coded for content and indexed. It is anticipated that this literature search is now 90% completed.

The bibliography of Thermophysical Properties of Fluorine from 0° to 300°K has been completed and issued as NBS Report 7676, dated April 1, 1963. A listing of 51 references, indexed by property, is included.

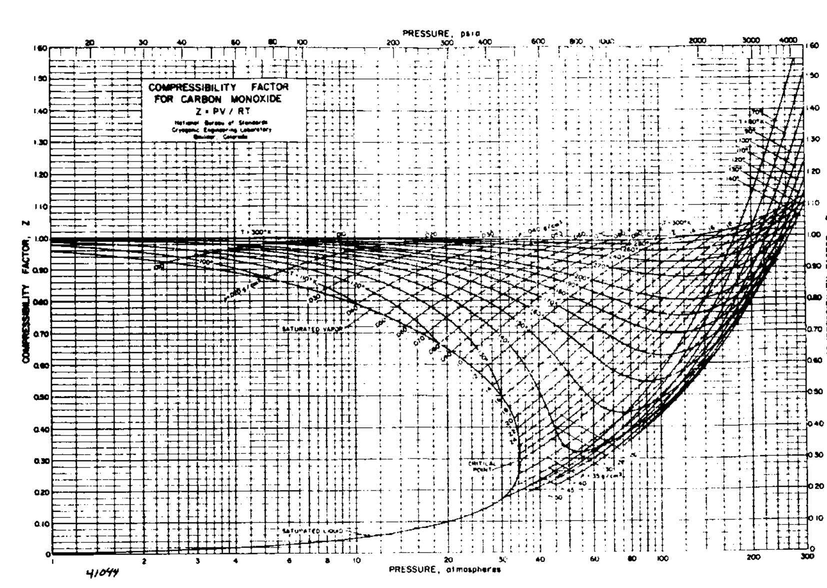
The bibliography on the Thermal Conductivity of Ten Cryogenic Liquids has been completed and issued as NBS Report 7684, dated April 15, 1963. A listing of 72 references, indexed by fluid, is included.

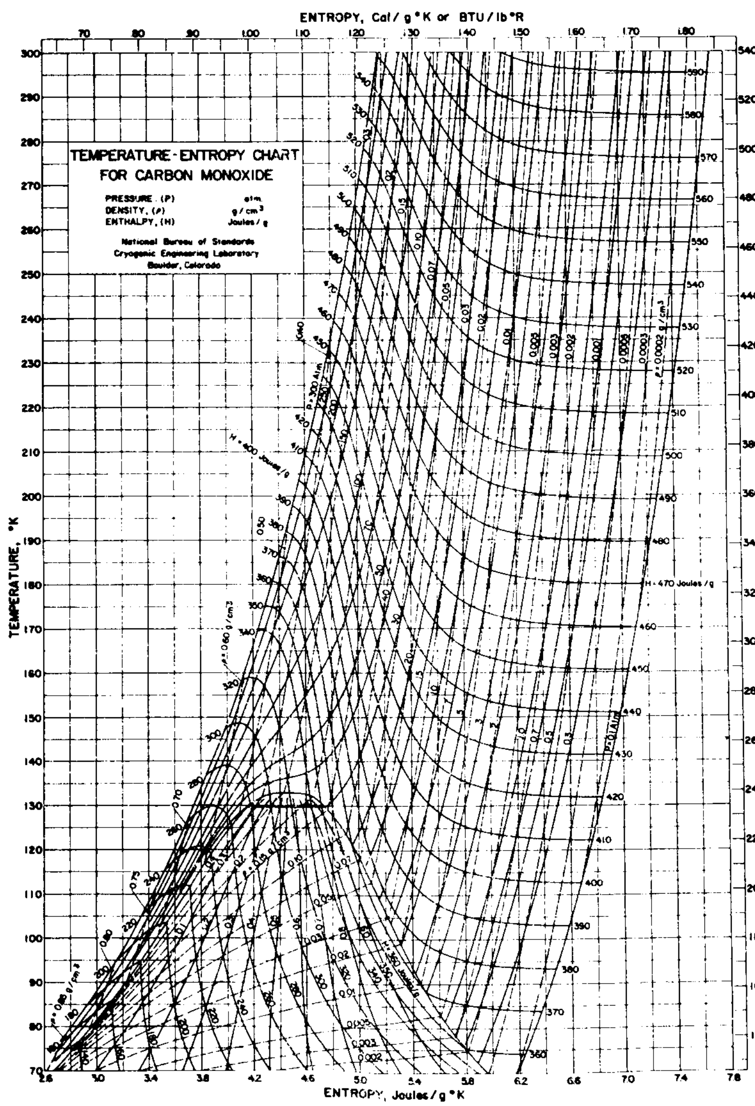
The preparation of a printed bibliography on the thermophysical properties of argon has been initiated in the current reporting period. Approximately 250 references have been obtained and coded.

A continuing awareness of the current scientific literature is being maintained in conjunction with the Cryogenic Data Center documentation unit. Copies of documents related to present and future tasks for the evaluation unit are being obtained and indexed. Additional bibliographies on selected topics, resulting from this activity, will be published periodically.

## 4.4 Summary Charts

Summary charts of all tasks under this project follow on the next two pages.


COMPRESSIBILITY FACTOR
FOR CARBON MONOXIDE
Z = PV / RT
PRESSURE, psia
PRESSURE, atmospheres
COMPRESSIBILITY FACTOR, Z
SATURATED VAPOR
SATURATED LIQUID
CRITICAL POINT
41044


TEMPERATURE-ENTROPY CHART
FOR CARBON MONOXIDE
PRESSURE, (P) atm
DENSITY, (ρ) g/cm³
ENTHALPY, (H) Joules/g
National Bureau of Standards
Cryogenic Engineering Laboratory
Boulder, Colorado
ENTROPY, Cal/g °K or BTU/lb °R
ENTROPY, Joules/g °K
TEMPERATURE, °K
TEMPERATURE, °R
H = 470 Joules/g



B-41044

## 4.4 Summary Chart, Project 81450

THERMODYNAMIC PROPERTIES OF CRYOGENIC FLUIDS

| | Helium | Neon | Oxygen | Argon | Carbon Monoxide | Para-hydrogen | Nitrogen |
|---|---|---|---|---|---|---|---|
| Priority Currently Assigned * | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Pressure Range (atm.) | 0.1 to 100 | 0.1 to 200 | 0.1 to 250 | undecided | 0.1 to 300 | 1 to 340 | 0.1 to 200 |
| Temperature Range (°K) | 20 to 300 | 25 to 300 | undecided | undecided | 70 to 300 | 20 to 300 | 65 to 300 |
| Phase Included** | 1 | 1, 2, 4, 5 | 1, 2, 4, 5 | 1, 2, 3, 4, 5, 6 | 1, 2, 4, 5 | 1, 2, 4, 5 | 1, 2, 4, 5 |
| Literature Searched, Summarized | X | X | X | X | X | Data Source: NBS Tech. Note 130 | Data Source: NBS Tech. Note 129 |
| Experimental Data Compiled | X | X | X | X | X | | |
| Data Evaluated, Best Values Selected | X | X | X | IP | X | | |
| Equation of State Determined | X | X | X | IP | X | | |
| Tables of P-ρ-T Values Determined | X | X | X | | X | | |
| Tables of Entropy, Enthalpy Calculated | X | X | X | | X | | |
| P-Z Diagram Constructed | X | X | | | X | | |
| T-S (H-S) Diagram Constructed | X | X | 2** IP | | X | X | X |
| Report Manuscript in Progress | | X | X | | X | | |
| Report Published | X | | | | | | |

*Fraction indicates portion of time devoted to task by one full-time professional staff member.

IP = in progress

** 1 - gas
2 - liquid
3 - solid
4 - saturated gas
5 - saturated liquid
6 - saturated solid

4.4 Summary Chart, Project 81450 (continued)

## ADDITIONAL THERMOPHYSICAL PROPERTIES

| | Surface Tension | Dielectric Constant | Electrical Resistivity | Saturation Properties |
|---|---|---|---|---|
| Priority Currently Assigned* | 1/2 | 1/4 | 1/4 | 3/4 |
| Materials Included | Cryogenic Fluids | Cryogenic Fluids | Pure Metals | Cryogenic Fluids |
| Phases Included** | 5 | 1, 2, 3 | 3 | 4, 5, 6 |
| Temperature Range (°K) | t.p. to c.p. | undecided | 0 to 300°K | |
| Literature Searched, Summarized | X | X | IP | IP |
| Experimental Data Compiled | X | X | IP | IP |
| Data Evaluated, Best Values Selected | X | | | |
| Analytic Equation Determined | IP | | | |
| Tables of Values Determined | | | | |
| Property Diagram Constructed | | | | |
| Report Manuscript in Progress | X | Data Summary Sheets | | |
| Report Published | | | | |

## BIBLIOGRAPHIES

| | Priority* | Literature Search Completed | Documents Coded | Manuscript in Progress | Report Published |
|---|---|---|---|---|---|
| Thermophysical Properties of Oxygen | 0 | X | X | | X |
| Thermophysical Properties of Fluorine | 0 | X | X | | X |
| Saturation Properties of Cryogenic Fluids | 1/4 | IP | X | X | |
| Thermal Conductivity of Cryogenic Liquids | 0 | X | X | IP | X |
| Thermophysical Properties of Argon | 1/2 | IP | IP | | |

* Fraction indicates portion of time devoted to task by one full-time professional staff member

** 1 - gas, 2 - liquid, 3 - solid, 4 - saturated gas, 5 - saturated liquid, 6 - saturated solid

IP = in progress

# 5.0 Research on Cooldown of Cryogenic Transfer Lines

W. G. Steward, J. H. Wilson, and W. H. Probert

## 5.1 Experimental and Semi-Empirical Studies

No further experimentation was performed during this quarter. Primary consideration was given to development of the theoretical methods for predicting cooldown time, surge pressures and flow rates. These analyses are referenced in the Eighth and Ninth NBS Progress Reports.

Modifications were made to the quasi-steady flow model for predicting cooldown time and average flow rates. The results of calculations made on the NBS computer for two revised models are shown in fig. 1. It can be seen that the maximum deviation of the theoretical values from the experimental data is about 20%. A wider range of test data is necessary to evaluate the theory fully and to indicate the need for further modification of the theoretical models.

The convergence problems for the surge analysis have been very persistent but the computer program now completes one surge cycle as desired. The results are encouraging as may be seen in fig. 2 in which the flow rate and pressure is plotted for one surge, and compared with the experimental data. It remains to be seen whether or not the theory will compare as well for other flow conditions.

Reports are being prepared on the two analyses and further experimentation is anticipated.

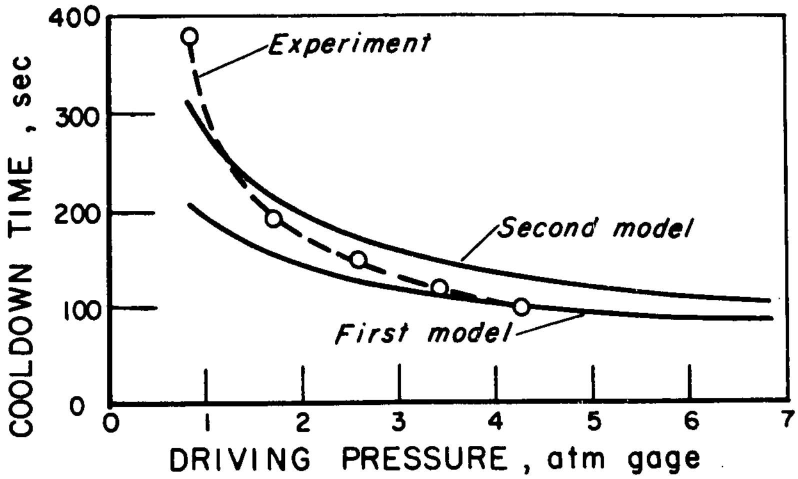



*Figure 1· Prediction of cooldown time as a function of driving time.*

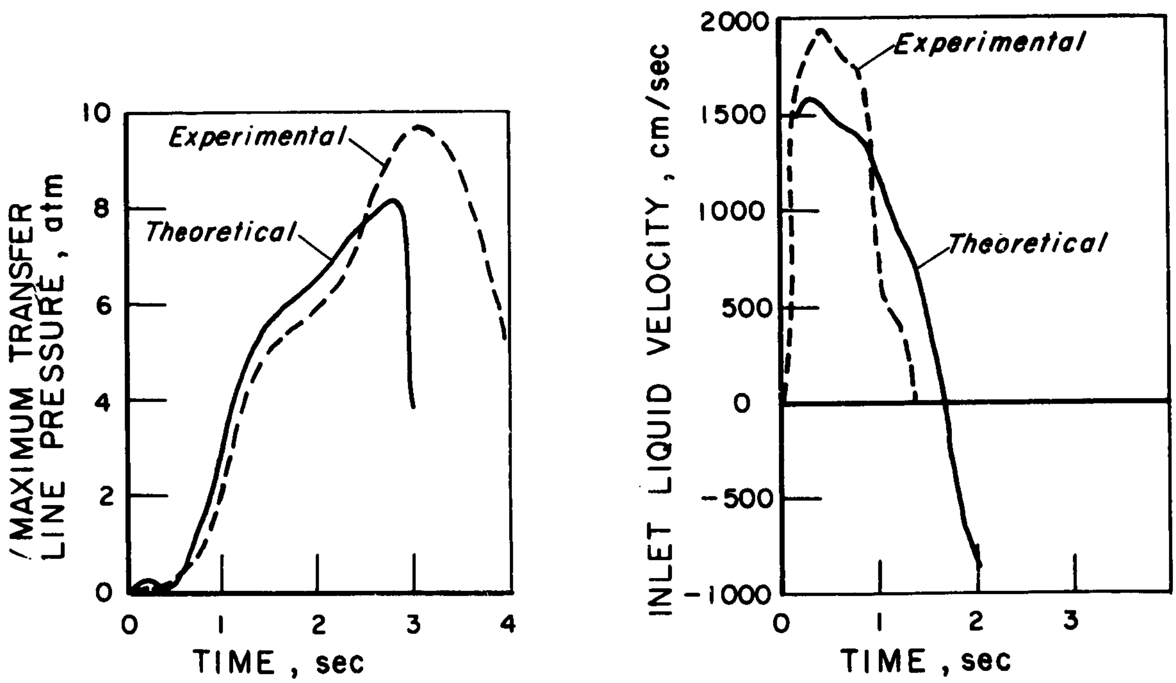


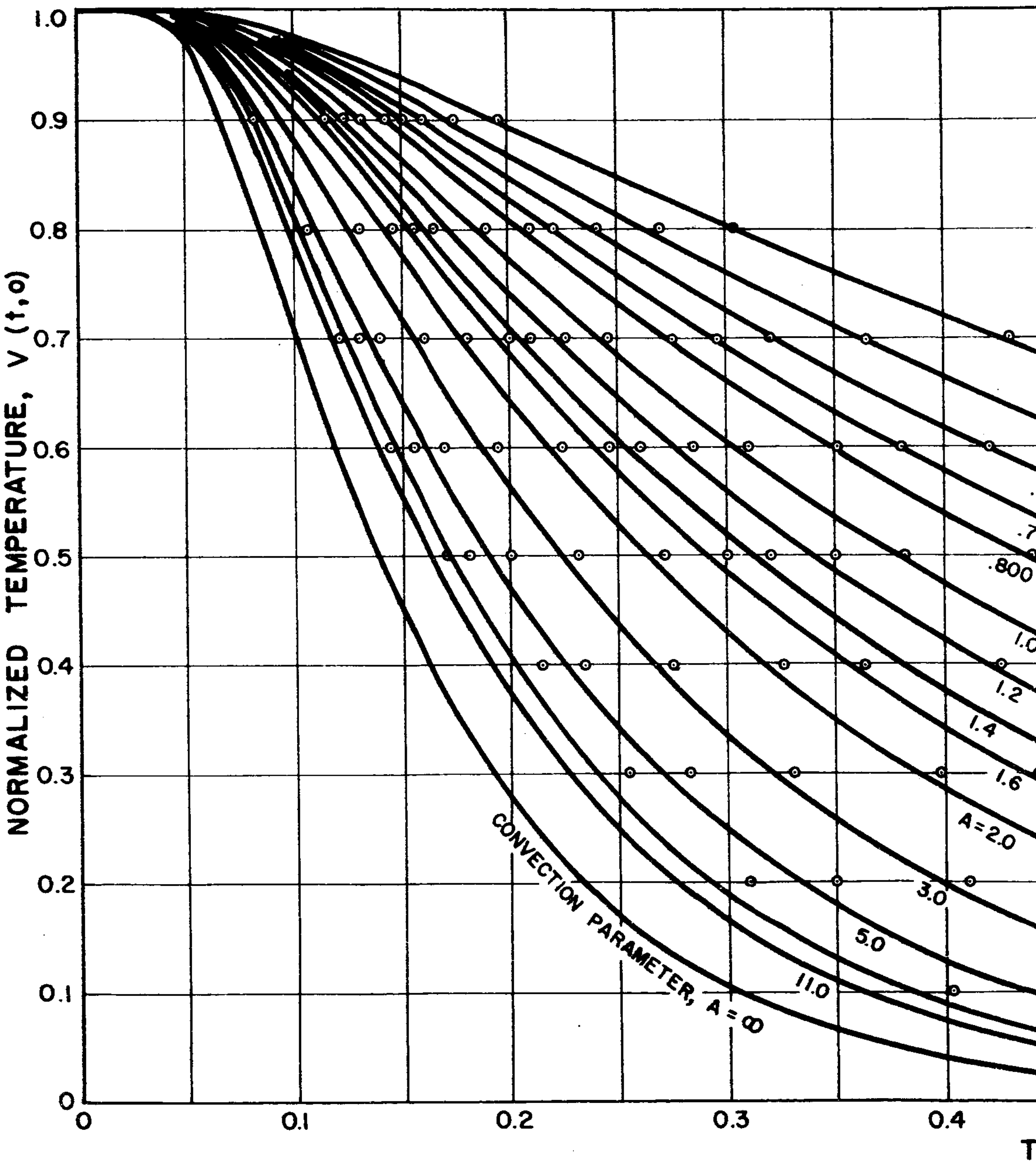

*Figure 2· Liquid nitrogen at 75.7°K entering a 200 foot long , 5/8" inside diameter, transfer line . Constant supply reservoir pressure of 50 psig ( 3.40 atm ).*

## 5.2 Theoretical Studies

The averaging necessary in the Lax method described in a previous report caused a diffusion of temperature and other variables which exceeded the change inherent to the problem; therefore, it has been abandoned.

The Courant Isaacson Rees* method has been coded and checked out on the computer. This method is described in Forsythe and Wasow, "Finite Difference Methods". Difficulties have been encountered in inverting a matrix with sufficient accuracy; revisions have been made to the program to avoid this difficulty.

* R. Courant, E. Isaacson, M. Rees. "On the Solution of Nonlinear Hyperbolic Equations by Finite Differences; Communications on Pure and Applied Math, Vol. V., 243-255 (1952).



NORMALIZED TEMPERATURE, V (t,0)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
CONVECTION PARAMETER, A = ∞
11.0
5.0
3.0
A=2.0
1.6
1.4
1.2
1.0
.800

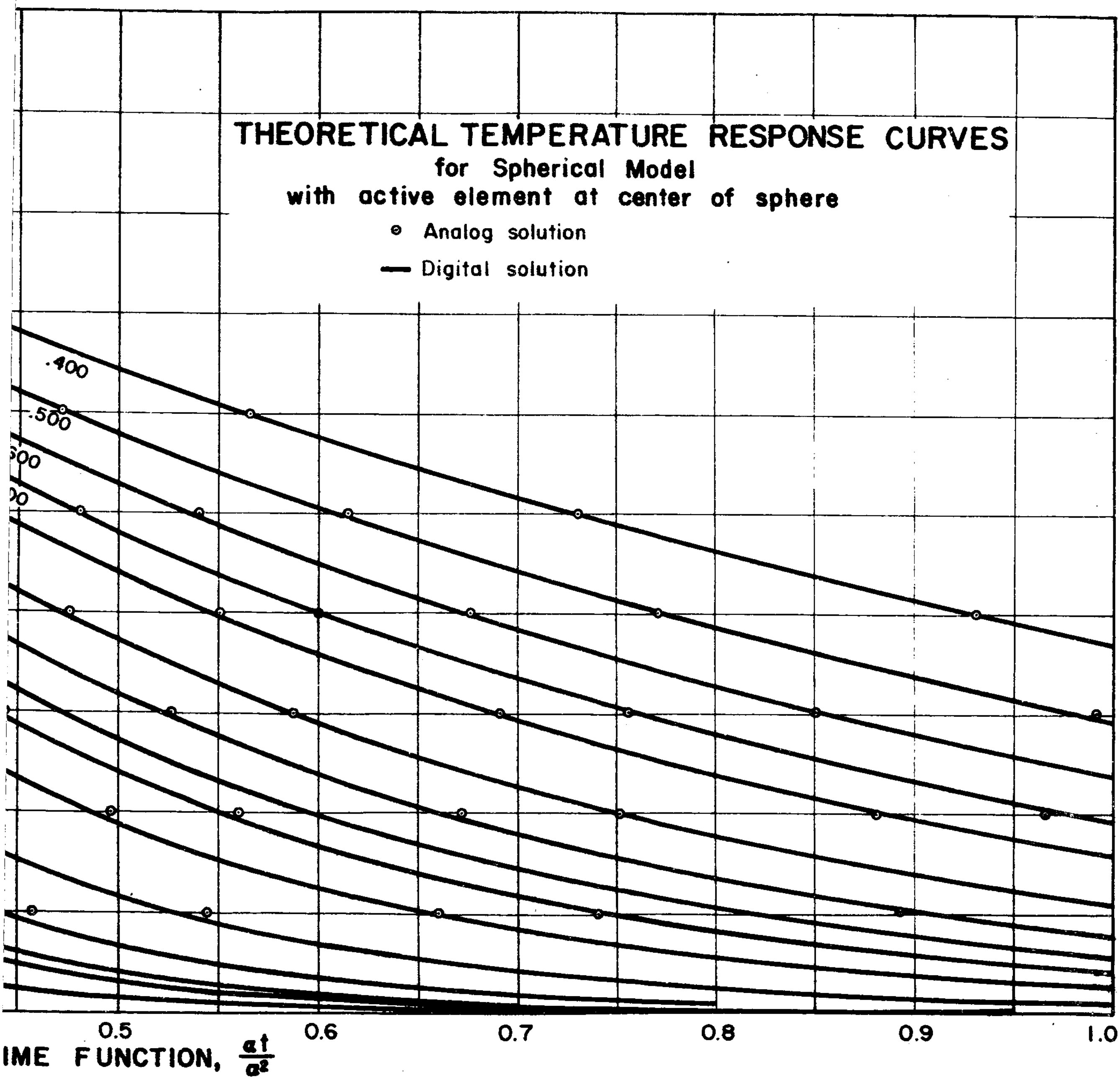

THEORETICAL TEMPERATURE RESPONSE CURVES
for Spherical Model
with active element at center of sphere
Analog solution
Digital solution
.400
.500
0.5
0.6
0.7
0.8
0.9
1.0
IME FUNCTION, $\frac{\alpha t}{a^2}$

FIG. 2.1.2